

Upper tropospheric tropical variations and trends in ozone and carbon monoxide: MLS and model results



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Goals/Methods

- **O₃ and CO are both important tropospheric pollutants**
 - > Influenced by biomass burning, convection, transport (CO tape recorder, *Schoeberl et al.*, 2006)
 - > Significant variability and uncertainties in trends in the troposphere
(e.g., *WMO* (2018), *Gaudel et al.* (2018), “Tropos. Ozone Assessment Report” papers)
- **2005-2017 MLS O₃ & CO upper tropospheric (UT) data are compared to SD-WACCM**
(Specified-Dynamics Whole Atmosphere Community Climate model, CESM2 version)
 - > MLS only measures at p < 215 hPa (CO) or 261 hPa (O₃) → UT only in the tropics
 - > We derive trends from data & model series, using Multivariate Linear Regression (**MLR**) : includes linear & constant terms + annual, semi-annual cycles, 3- and 4-month cycles, two QBO terms (eq. winds at 30 & 50 hPa), ENSO (MEI index) and solar (10.7 cm flux) terms
 - > Analyze zonal means as well as lat./lon binned data sets
- **Recent model changes: CESM2 (SD-WACCM) run extended through 2017**
 - > MERRA-2 meteorological field constraints rather than MERRA
 - > Updated convection routine, radiative transfer, aerosol scheme
 - > Improved halogen source species distribution (time & lat.-depend. - as for CO₂, CH₄, N₂O)
 - > CO and VOC emissions from CMIP6 (Coupled Model Intercomparison Project) baseline
 - Model could use further refinements
(e.g., anthropogenic CO emissions & other emissions post-2014, realistic SSTs for 2017)

Sample time series comparisons and fits for zonal mean UTLS O₃ : Equatorial region

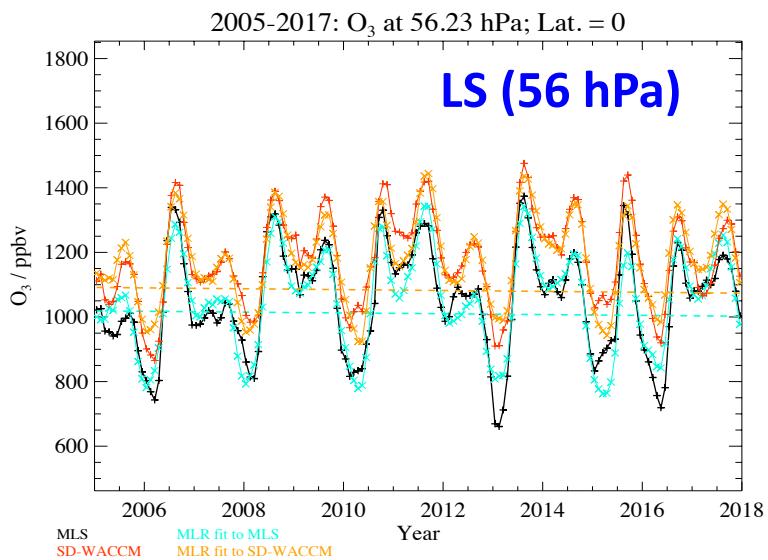
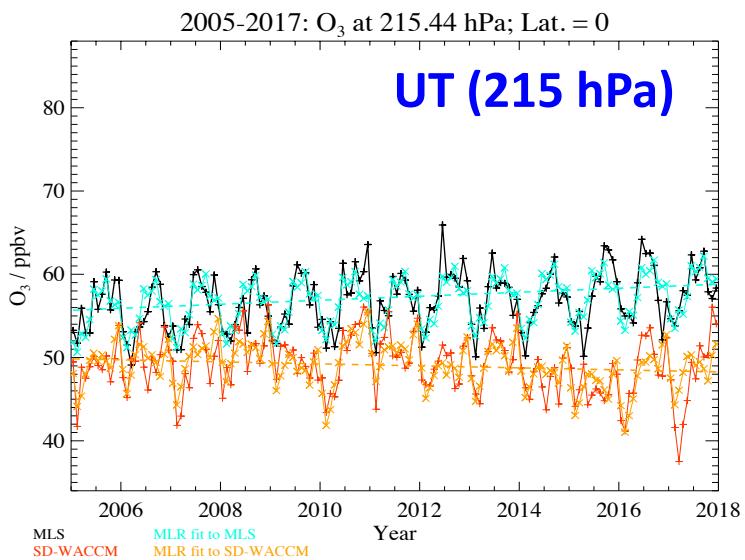
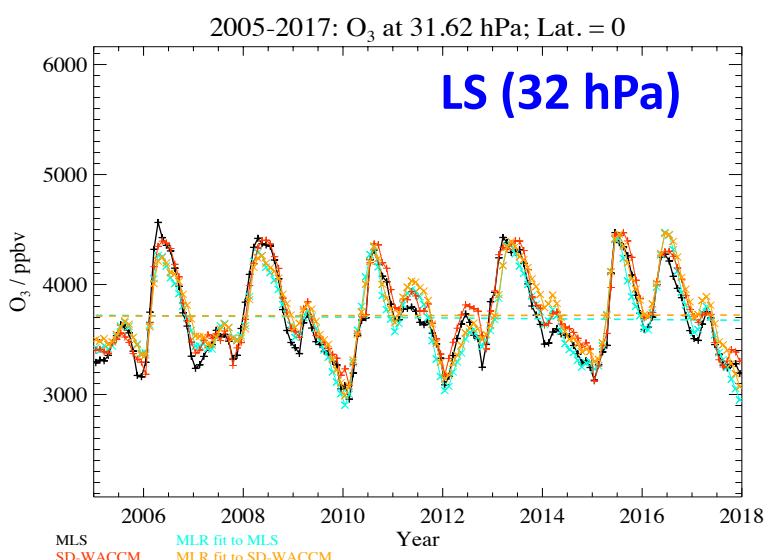
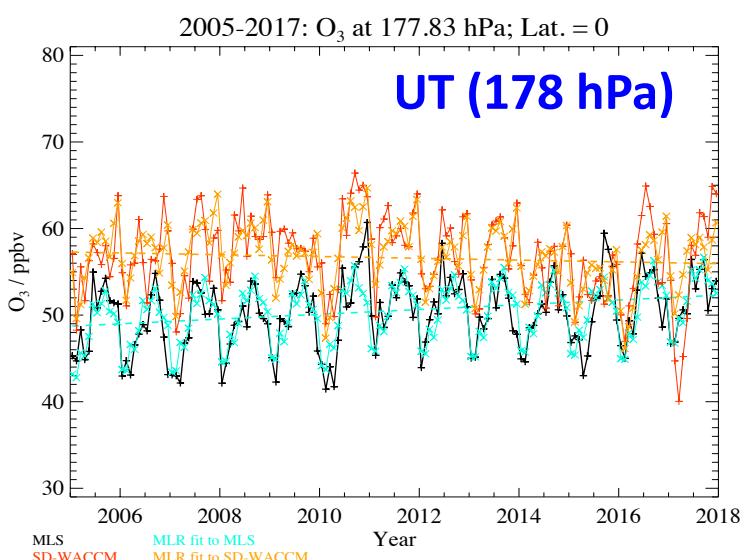
MLS

Fit to MLS

Model

Fit to model

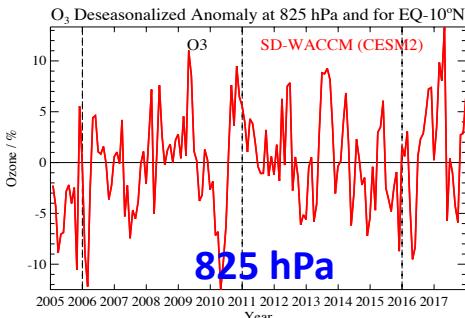
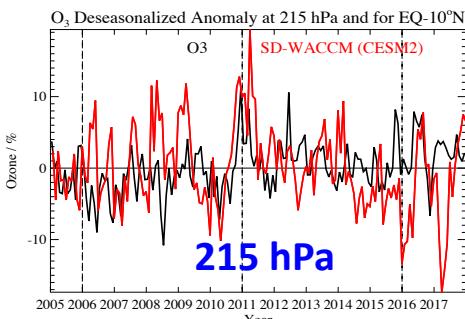
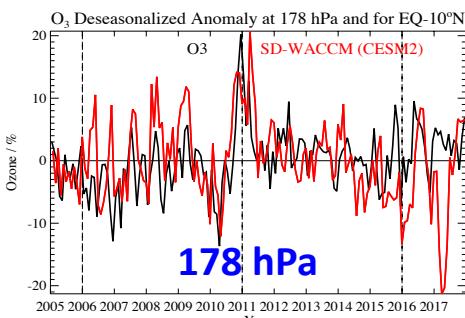
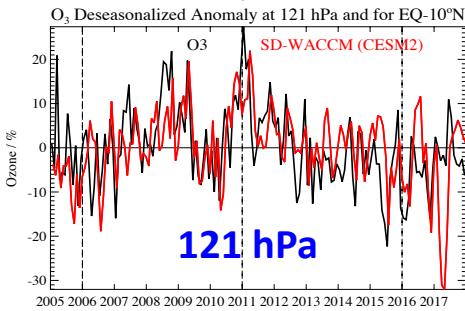
Dashed lines are the linear trend components (for MLS and model)



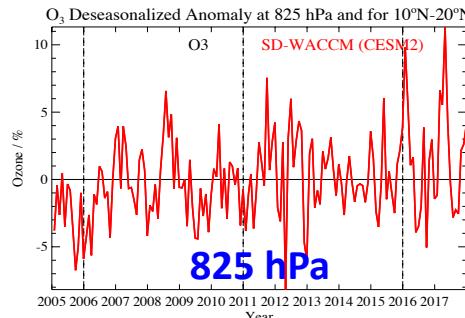
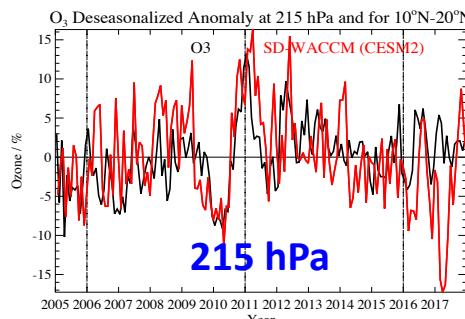
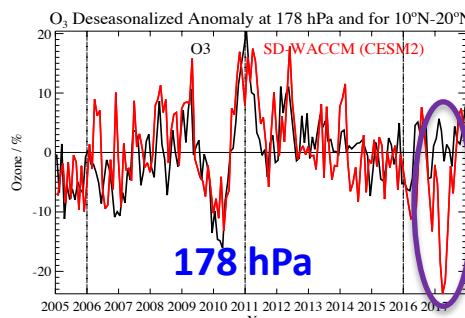
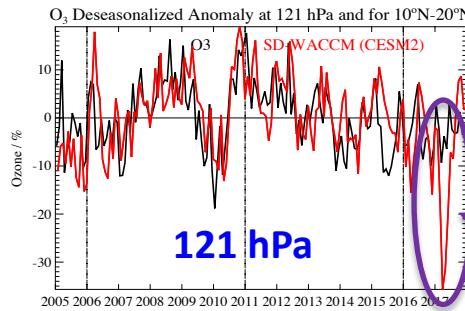
- The 2 plots at left show some discrepancies between **SD-WACCM** & **MLS UT** trends for 2005-2017
 - > In the UT, the **model** shows some **decrease**, while **MLS** shows some **increase**
 - > In the **LS** (2 plots at right), there is generally excellent agreement between the model and data

Sample time series comparisons: zonal mean UT O₃ anomalies for EQ-10°N and 10°N-20°N

EQ-10°N



10°N-20°N



MLS ozone anomalies

SD-WACCM (CESM2) anomalies

Model fits are generally better for 2005-2014

- Negative model spikes/anomalies in 2017 play a significant role in neg. model trends

> wrong SSTs in the model's 2017 extension

> spikes disappear if use the correct SSTs
(not shown here)

- Note that in the lower troposphere (see the 825 hPa panel), there is an apparent increase (or no significant decrease)

- Tropical UT variability is significantly affected by ENSO, longitudinally as well (with related changes in humidity, convection, circulation)

> e.g., Chandra et al., 1998; Oman et al., 2011
> for 2009-2010 El Niño, see Oman et al., 2013

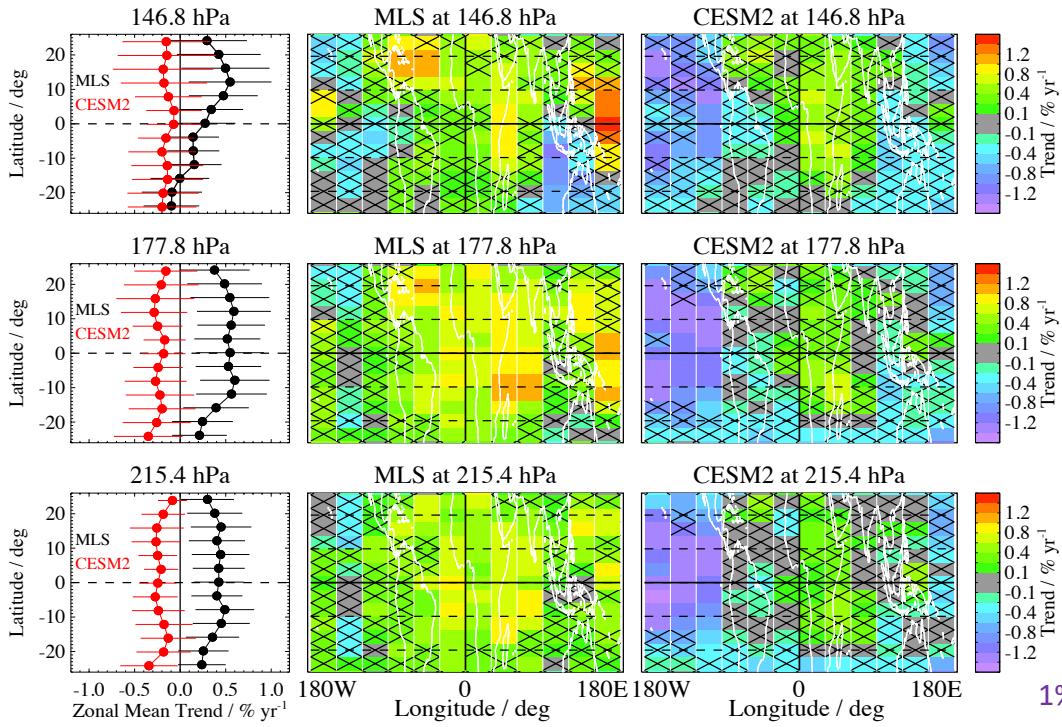
- More generally, convection, biomass burning, CO, VOCs, NOx, HOx, lightning, and strat-trop exchange can influence the UT O₃ balance

UT Tropical Ozone Trends: MLS and SD-WACCM zonal mean and lat./lon. results

- MLS zonal mean tropical UT O_3 trends are slightly larger in NH than in SH (not unlike total col. data tendency, WMO, 2018)
- Model zonal mean results show (small) decreases instead, driven by mostly negative trends over the Pacific
- MLS gridded data (30° lon x 4° lat) yield some **positive UT trends** over Africa, Atlantic, Indian Ocean, S.E. Asia
- SD-WACCM gridded data show **+ trends** over Africa (mainly); weaker trends than MLS; significant **neg.** Pacific trends

Tropical Upper Tropospheric Ozone Trends: 2005-2017

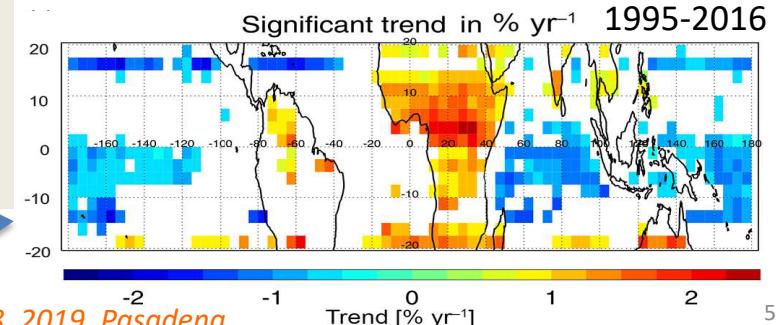
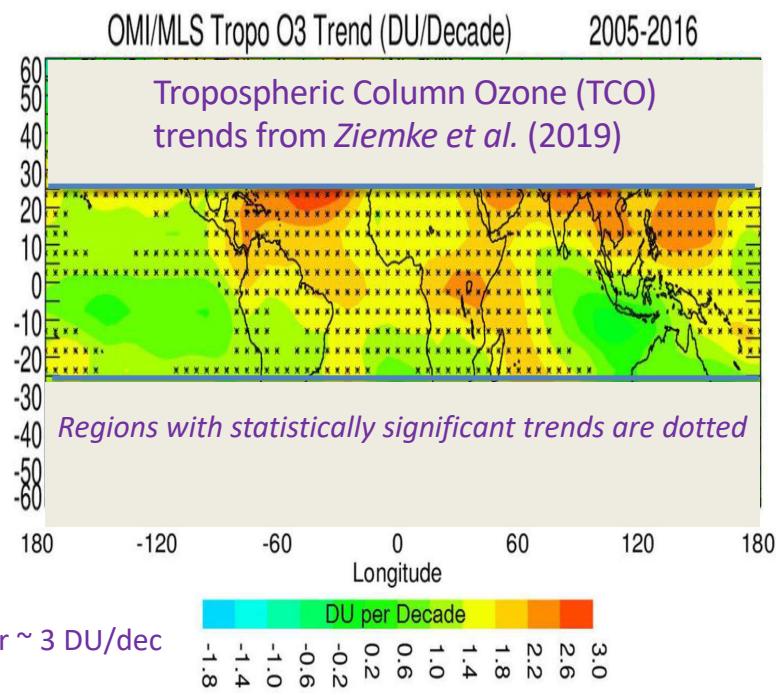
(but note changes to trends/fits for different periods)



Regions with no significance in trends are crossed out

There are broad similarities between the above MLS patterns of positive UT O_3 trends and the tropical OMI/MLS Trop. Col. O_3 trends of Ziemke et al. (2019), who find little Pacific decrease
- but they find that tropical TCO change has accelerated in 2005-2016

See also the TCO trend results from Leventidou et al. (2018)
- use several TCO data sets (1995-2016), various merging approaches

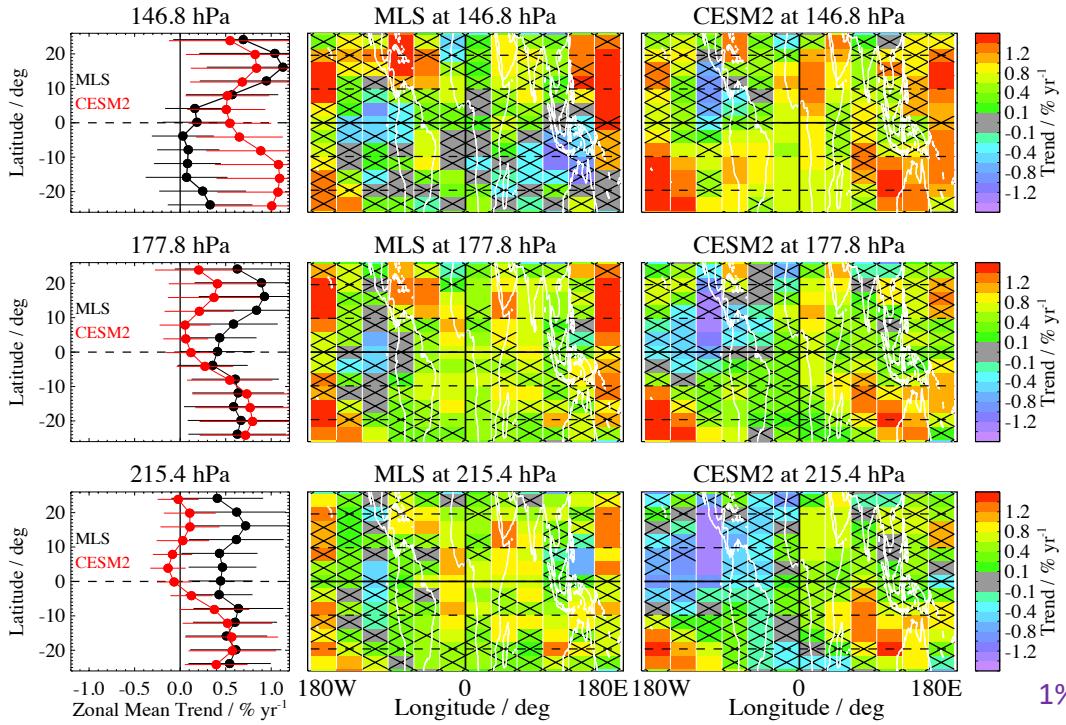


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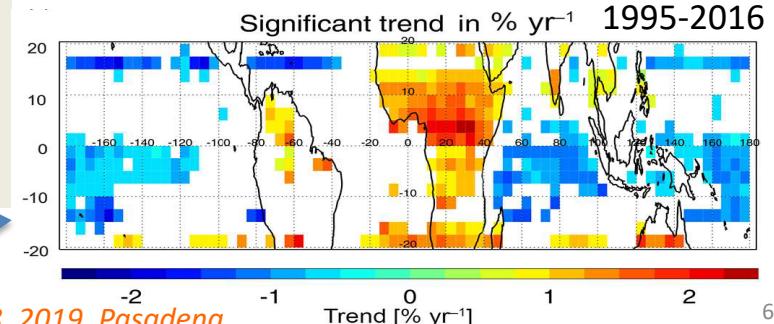
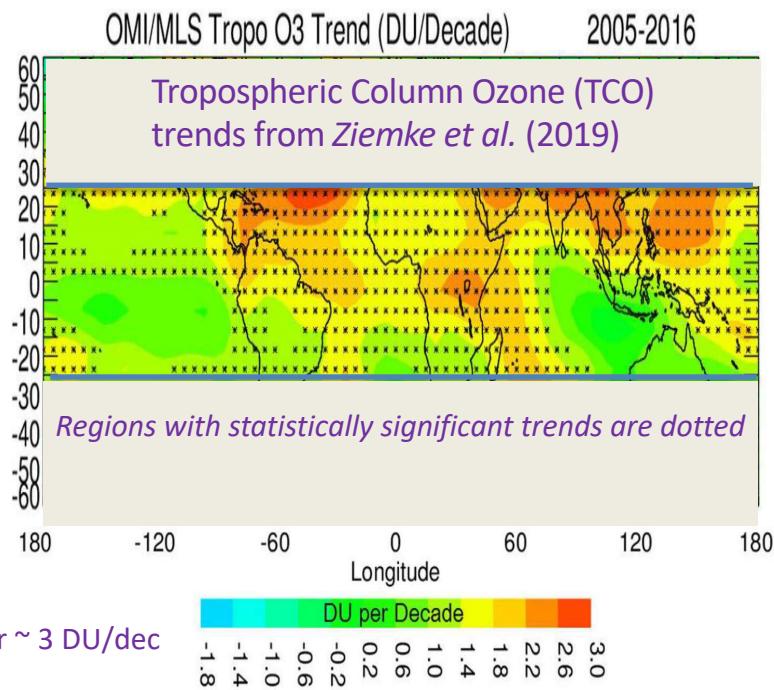
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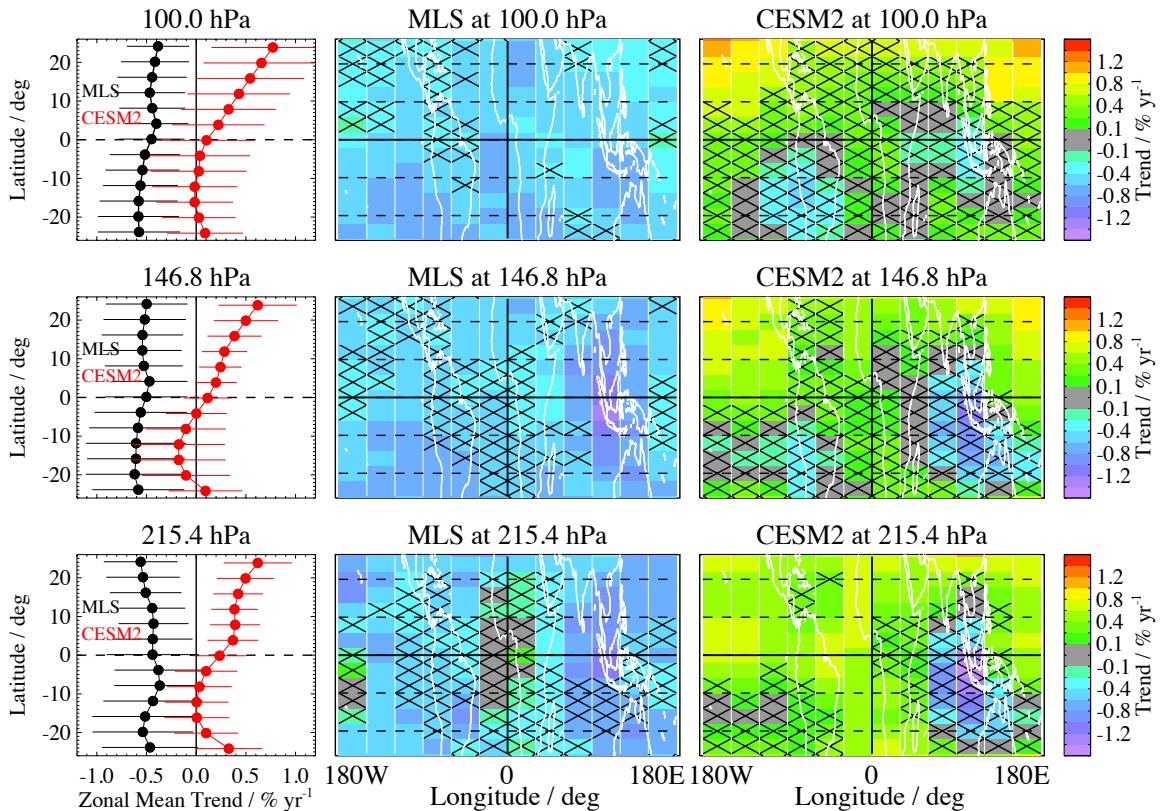
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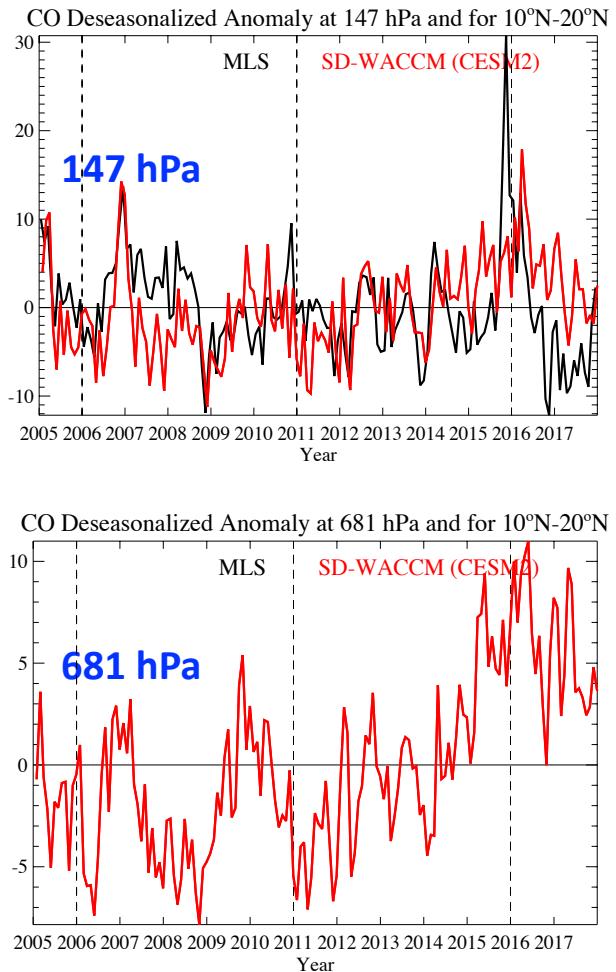


UT Tropical CO Trends: MLS and SD-WACCM: Zonal mean and Lat./Lon. results

Tropical Upper Tropospheric CO Trends: 2005-2017



CO Anomalies for 10°N-20°N



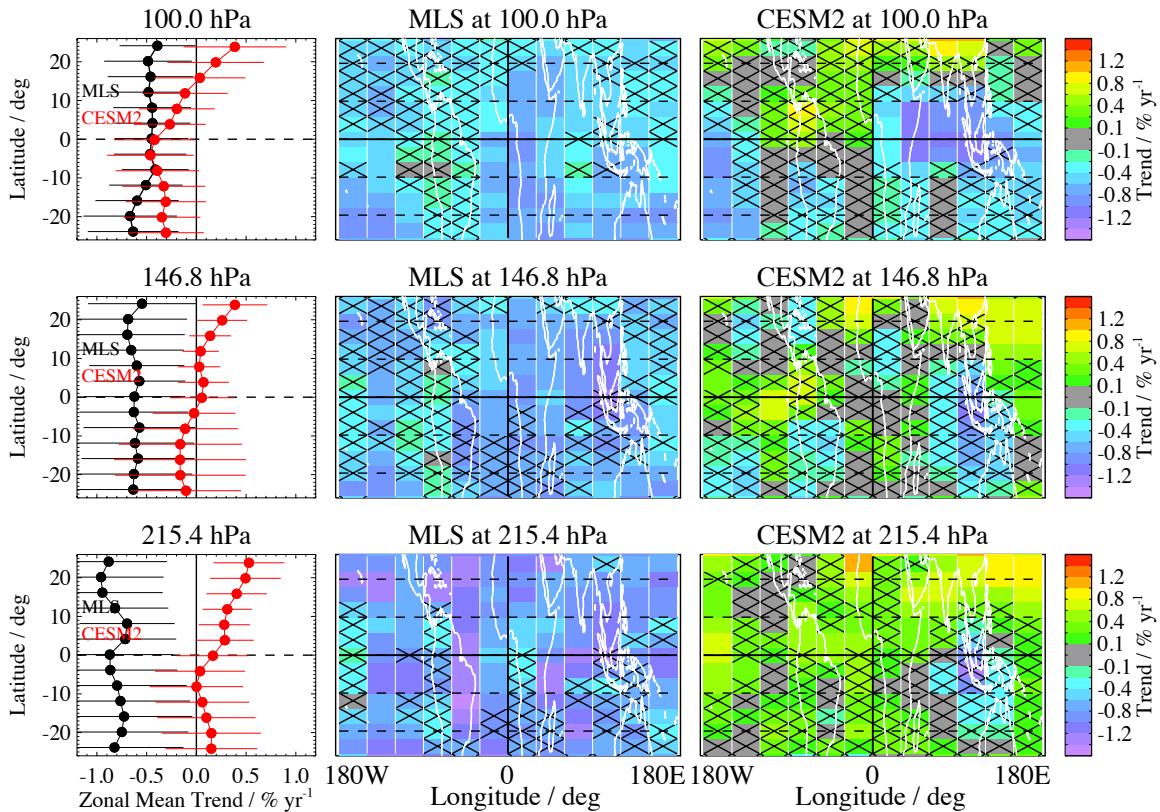
CO: MLS UT zonal mean trends $\sim -0.5\%/\text{yr}$

SD-WACCM: near-zero/slightly positive trends; also, + trend in lower troposphere (681 hPa, right panel).

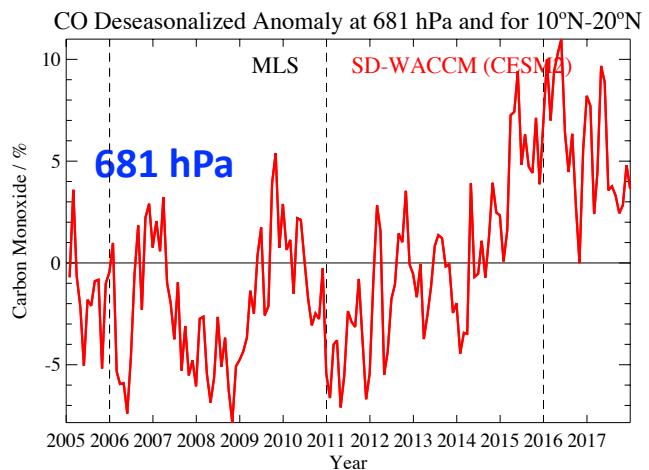
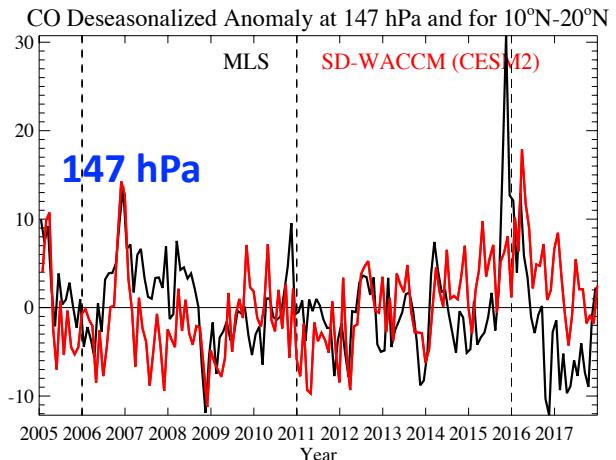
- Besides El Niño-related increases in late 2015 and for some time thereafter, fairly subtle differences between SD-WACCM & MLS series lead to the trend diffs. (see top right zonal mean plot for 10N-20N at 147 hPa).
- MLS gridded trends show a bit less variability than O₃; SD-WACCM gridded results are positive, when significant.
- Not too much change versus 2005-2014 period. Less impact on CO than O₃ if use correct 2017 SSTs (not shown).

UT Tropical CO Trends: MLS and SD-WACCM: Zonal mean and Lat./Lon. results

Tropical Upper Tropospheric CO Trends: 2005-2014



CO Anomalies for 10°N-20°N



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Main Conclusions: A tale of two species

Tropical UT trend analyses	Ozone	Carbon Monoxide
MLS zonal means (2005-2017)	about 0.3 to 0.5%/yr	about -0.5%/yr
CESM2 zonal means (2005-2017)	near-zero to -0.3%/yr	-0.1 to +0.6%/yr
MLS gridded (2005-2017)	regional variability with some trends > +1%/yr	generally negative trends
CESM2 gridded (2005-2017)	a few positive regional trends, negative trends over Pacific	some slightly positive trends (where significant)
Comments	<ul style="list-style-type: none"> - Better agreement for 2005-2014 > <u>strong sensitivity to SSTs</u> in end year - Past tropospheric O₃ trend results show large differences and scatter <ul style="list-style-type: none"> > several satellites → + TCO trends over East Asia (<i>Gaudel et al., 2018</i>) > MOZAIC-IAGOS → + UT O₃ trends at NH mid-lats (<i>Cohen et al., 2018</i>) > sondes (e.g., <i>Cooper et al., 2014</i>) - MLS/sonde validation in tropical UT → good agreement despite scatter (see also <i>Gebhardt et al., 2014</i>) - Notes: O₃ surface precursors exhibit large variations and trends <ul style="list-style-type: none"> > Total column O₃ has not increased significantly (<i>WMO, 2018, Chap. 3</i>) 	<ul style="list-style-type: none"> - Generally similar level of (dis)agreement for 2005-2014; model CO emissions to be re-examined - MOZAIC-IAGOS → negative trop. CO trends at NH mid-latitudes (<i>Petetin et al., 2016; Cohen et al., 2018</i>) - Note: Nadir-viewing satellite data sets → <u>lower trop.</u> CO has decreased globally (<i>Worden et al., 2013</i>) (although does not seem to show in <u>UT</u> MOPITT/AIRS data)
Other Notes: Potential causes		
Tropical UT O ₃ increases:		
> some decreases in surface NO _x emissions (<i>Ziemke et al., 2019</i>)		
> dynamics, strat/trop transport? (note that O ₃ has a somewhat longer lifetime than CO)		
Tropical UT CO decreases:		
> decreases in CO emissions are a likely cause (although changes at surface are quite inhomogeneous)		
<i>Disclaimer: Results may not properly represent underlying long-term trends, given the length of the records considered (2005-2017).</i>		